A study of diagram 3 (fig. 6) shows that if the evaporation from the instruments be increased by such factors that at the highest point their losses approximately equal the total transpiration, (1) all except the white porous cup show a sharp decline with the first decline in transpiration; (2) the white porous cup shows its dependence at all times on atmospheric conditions rather than on "sun" temperatures; (3) the porous cups and Piche types show five to seven times as much evaporation at night as do the trees; (4) the Type 4 "sun" instrument more closely follows the trees at night because dependent, like them, on radiant energy rather than heat of the air.

These are essentially the same relations shown by the comparative behavior in different kinds of days.

SUMMARY.

The Type 4 "sun" wick evaporimeter represents the most complete development of an effort to duplicate by mechanical construction the physical features of the plant which control basically its response to evaporation stimuli. The important features, physically, are (1) the blackened surface of the cover, absorbing the energy of sunlight to a high degree, and transmitting this energy by conduction through brass to the moist wick immediately beneath and in contact with the cover; (2) the position of the wick, removed from immediate contact with the outside atmosphere, so that the air itself is not an important source of heat for evaporation, and so that vapor formed between the disk perforations, corresponding to stomata, does not diffuse too readily to the outer atmosphere.

These features permit the type 4 wick evaporimeter to follow plants, through wide variations in sunlight and air movement, more closely than any other atmometer which has been used or tested in the present case. Moreover, under rather uniform conditions, from day to day, the relations of evaporation to transpiration, with this instrument, are more consistent than with others, in spite of the fact that the actual losses are relatively small and the possibility of variations due to inaccuracy in weighing proportionately great.

The "shade" or polished-top evaporimeter of Type 4 possesses no advantages over the "sun" instrument, and the operation of the two phases side by side offers no possibilities as a means for measuring sunlight intensities, or even as a means for showing the extent to which plants are influenced by sunlight.

The essential points in the operation of the Type 4 evaporimeter are:

1. The use of distilled water.
2. Replacement of wicks whenever they become soiled at the edges or at the points most directly exposed to the air.
3. The use of heavy damask for wicks, because of its strong capillary properties and large capacity.
4. Calibration whenever it becomes necessary to replace wicks or to remove the cover.
5. Firm placing of the cover to obtain close contact with disk wick.
6. The use of scales having a capacity of 1 kilo and a sensitivity of 0.1 or 0.2 gram.
7. In freezing weather it is preferable to maintain the water in the tanks at the lowest level commensurate with the needs of daily or weekly evaporation periods. It is never desirable to fill the tanks to capacity.
8. Lampblack mixed with turpentine to the consistency of a thin paste, and applied with a camel's-hair brush, is the best coating for covers so far tried. It should be retouched or replaced whenever any considerable area of the nickeled surface shows through. Ordinary paint, with a luster, should be avoided. Certain "dead-black" paints are fair substitutes for lampblack.
9. The exterior polished surfaces of the instrument should be kept clean so that they do not become absorbers of insolation in any marked degree.
10. The instruments are preferably placed on the ground, or, if above the ground, in baskets which do not create any artificial reflecting surfaces below the disk, other than those of the instrument itself.

The present development has produced an instrument which is eminently practical in addition to integrating solar and atmospheric conditions in much the same way as does the plant. No new difficulties are encountered in attempting to use it for year-long climatological studies.

LIST OF REFERENCES.

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2. BURNS, G. P., and HOOPER, F. P. "Studies in Tolerance of New England Trees: II. Relation of Shade to Evaporation and Transpiration in Nursery Beds." (Vermont Agr. Exp. Sta., Bull. 181, 1914, Forest Service Publ. No. 15.)
3. LIVINGSTON, B. E. "Atmospheric Influence on Evaporation and its Direct Measurement." (MONTHLY WEATHER REVIEW, March, 1915, vol. 43, pp. 126-131.)

(This is only one of the latest of numerous papers by the same author describing the porous cup atmometer, and contains a fairly complete list of other references on the subject of atmometry.)

THE MEASUREMENT OF RAINFALL AND SNOW.

By ROBERT E. HORTON, Consulting Engineer, Albany, N. Y.

[Abstract from Journal of the New England Water Works Association, 1919, vol. 33, no. 1, pp. 14-71, 21 figs., 12 tables.]

SYNOPSIS.—"The object of this paper is to describe methods of measuring rainfall and snow, and to discuss the errors and accuracy of such measurements, with a view to suggesting methods of securing rainfall records having the highest possible degree of accuracy and usefulness. Some attention will be given to the question of the reliability of the results obtained from a single raingage as applied to larger or smaller areas around it."

This thorough paper on the measurement of rainfall and snow opens with a discussion of the history of rain gages and of early observations, particularly those of the United States. Detailed descriptions of various forms of rain gages follow. Passing over many of these details, this review will cover particularly (1) errors of rainfall measurements, (2) suggested methods for the accurate measurement of snowfall, and (3) rainfall on mountain slopes as compared with raingage indications.

"ERRORS OF RAINFALL MEASUREMENTS.

"The usual errors to which rainfall records are subject include:

"1. Observational errors, personal equation, and mistakes.

"2. Instrumental or ratio error.

"3. Errors due to evaporation.
"4. Errors due to inclination of the gage funnel.
"5. Wind or exposure error.
"6. Location error.

"*Observational errors.*—The most usual observational error arises from recording the nearest hundredth inch less than the true amount, and from counting as traces all quantities less than 0.01 inch. If the observer will follow the rule of recording the nearest hundredth inch, whether greater or less than the true amount, and of counting as 0.01 inch any quantity greater than 0.005 inch and less than 0.015 inch, this error will be wholly obviated. As to mistakes—those of excess are apparently as likely to occur as those of deficiency."

There are many points about the reading and inspection of raingages that need attention. At most cooperative stations the raingages are read only once a day; and, unfortunately, some are read in the morning, and others in the afternoon. This makes local intercomparisons difficult. The frequently-found occurrence of certain irregularities in rainfall records, such as a lack of entries of traces, 0.01 or 0.02 inch, point to careless methods of observation, and indicate the need for much more frequent inspection of rainfall stations and talks with the observer. The need of keeping comparative records for a time when the location of the raingage is changed, and the value of no interruptions in rainfall records are readily appreciated without further discussion.

Instrumental error.—The selection of the proper type of raingage is the first consideration in providing an instrument which will record as closely as possible the actual amount of rainfall. "If it is assumed that a [cylindrical] gage can not catch more than [the] true amount, unless from outside causes * * *" a considerable amount of comparative data seem to indicate that 8 inches is the optimum diameter, notwithstanding the fact that some experiments have indicated that the catch of 8-inch gages is about 5 per cent less than the true rainfall. Among the recording types, the float or weighing gages give the most accurate results. Nevertheless, the total readings of gages of the tipping bucket type can be accurately checked by later measurements of the water retained in the gage.

A raingage itself may give erroneous measures of correct catches if the ratio between the size of the measuring tube and that of the funnel is not exactly that for which the measuring scale was graduated.

Evaporation loss.—Evaporation loss is usually negligible. The evaporation of water in the gage even in summer amounted in one test to only 0.01 inch in a week. The evaporation of the water that sticks to the funnel is in each instance equivalent to only about a third of 0.01 inch. In inaccessible regions where raingages must be left unvisited for considerable periods the use of a film of oil will prevent the evaporation of heavy falls of rain but facilitates the evaporation of water from light showers in which the water does not penetrate the oil.

Inclination errors.—With rain falling vertically gages at inclinations of 5°, 10°, and 15° will catch 0.4, 1.5, and 3.4 per cent less than they should. As rain does not usually fall vertically, however, "the effect of inclination of a raingage depends on the direction in which it is inclined relative to the direction of the rain-bearing wind. If the inclination of the gage is toward the wind and is less than twice the inclination of the rain, the gage will catch more than the true amount. * * * Since the rain does not always come from the same direction it is evident that an inclined gage may give results considerably in error in some showers and be quite nearly correct in other showers."

Wind or exposure error.—It has long been recognized that the decrease in the catch of gages with increased altitude above the surface is the result of wind action. In England raingages are exposed in grass-plots at least 6 feet in diameter and far enough from obstructions to give a fair catch. The top of the gage is 1 foot above the ground. In Germany raingages are at a height of 1 meter. In the United States, 4.5 feet has been found most satisfactory because of the greater susceptibility to (non-meteorological) disturbance at a lower elevation. Unless some sort of shield is provided to prevent upward air movements over the funnel, any gage, otherwise well-exposed as regards surrounding trees and buildings, may give unsatisfactory results. As shown by experiments in Russia, the deficiency may amount to perhaps 1 per cent in heavy rains, from 8 to 15 per cent in light rains, 18 to 20 per cent for wet snow, and 15 to 69 per cent for dry snow. At Providence, R. I., in the years 1909–1916, inclusive, five city gages showed mean rainfalls of from 39.42 to 41.51, while the gage on the roof of a tall building showed only 34.78 inches. This, however, is an extreme case. The catches of roof gages in other cities seem generally to be fairly close to those obtained at ground stations. The comparisons of 5 gages in Providence, 4 in Pawtucket, 6 at Fall River, and 8 in New Orleans show that the indications of any single gage under favorable conditions is generally within 5 per cent, and otherwise within 10 per cent, of the mean of all the other gages, in any single year. "[All in all,] the result of wind or exposure error is to make the recorded precipitation usually less than the true amount."

Location error.—A raingage may represent the amount of rain that falls in its immediate vicinity; but its indications are wanted to show the rainfall over an appreciable area, perhaps several square miles. "The result of error due to location of the raingage within the influence of a large wind eddy, is to make the recorded amount either greater or less than the true precipitation in the locality."[1]

Summary.—"Taken altogether, there is some preponderance of errors tending to make the measured less than the true amount of precipitation falling as rain, and the tendency is greatly increased for precipitation falling as snow."

SNOWFALL MEASUREMENT.

The measurement of snowfall is perhaps the weakest point in our precipitation records. It has long been recognized that most gages are useless for obtaining accurate snowfall measurements, even when fitted with a melting device. A new cylindrical snow sampler, diameter 8, length 30 inches, with a brass cutting rim, and a stopcock to let out the air when a cylinder of snow is being cut, has recently been devised by the author.

"Select a level space surrounded by shrubs or sparse trees. The open space or clearing should be 50 to 100 feet or more in diameter, depending on the height of the shrubs or trees. As a rule, snow will not drift nor be blown away near the middle of such a park or open space. In selecting the spot for snow measurement it is preferable to observe the conditions for a year in advance of its use. When snow falls at an angle, as it commonly does, a tree shadows the ground for some distance to the leeward and prevents the full depth of snow from reaching the ground. The spot chosen for making measurements must be suffi-

[1] Cf. Mo. Wea. Rev., 1915, 43: 318-321.—ed.

ciently remote from all trees to avoid an error from this source.

"Before the first snowfall, place on the ground a sheet of very thin board—plaster board or beaver board answers well. On the upper surface there should be secured by thumb tacks at the corners a sheet of white cloth with a rough surface—white flannel is good. The position of the board may be marked by two or three stiff wires stuck into the ground at a little distance from the board. When the first snowfall comes, a special snow can, described above, may be inverted over the cloth and pressed down firmly, rotating it slowly as it is pressed down. Then the remaining snow should be brushed off from the cloth, the board lifted, at the same time lifting and inverting the can with the board over its mouth. * * *.

"After a measurement the flannel cloth is, if necessary, dried, retacked on the snow board, and the snow board placed on the surface of the newly fallen snow where the snow is undisturbed, the board being pressed down just sufficiently so that the cloth surface is flush with the snow surface. The snow board should be inspected every day whether it snows or not, so as to keep its surface flush with the snow surface at all times.

"The use of the cloth is twofold: (1) It provides a surface with friction conditions much more closely resembling those of snow than could be obtained by the use of the board alone. (2) It provides a surface as nearly as can readily be obtained, equivalent to a snow surface in its capacity to absorb and radiate heat, and so prevents loss by melting when snow falls in relatively warm air."

Snow samplers of another type for measuring mountain accumulations of snow in spring are very useful for estimating a summer water supply.[3]

RAINFALL ON MOUNTAIN SLOPES AS COMPARED WITH THEORETICALLY PERFECT RAINGAGE INDICATIONS.

"There is a matter in connection with the inclination at which rain falls, which is sometimes of great importance, but which seems to have been generally overlooked. If a rain-bearing wind blows against a mountain slope, then the amount of rain falling on the mountain slope will generally be greater than the amount which would fall on an equal horizontal projected area and greater than the amount caught or measured by a horizontal rain gage.

"In a similar manner the actual precipitation on the leeward side of the slope may be materially less than indicated by a horizontal rain gage. The southeast slope of the Catskill Mountains in New York State affords an excellent illustration of a case where the actual rainfall is apparently greater than the measured amount. The average slope of the mountain side is about 30°. If the rain is blown against this slope at an angle of 15° to the vertical, then the actual precipitation on the projected area would be 1.16 times the amount measured by a horizontal raingage.

[3] A discussion of these is planned for a later issue of the REVIEW.—ED.

"If the run-off of a stream for the winter period, November to April, inclusive, is compared with the measured precipitation for the same period, it will sometimes be found that the measured run-off is the greater. However, the ground water and surface storage is usually larger at the end than at the beginning of the winter period, so that the measured run-off will usually represent less than the total available water supply."—*C. F. B.*

DISCUSSION.

Ever since, and in all probability before, the famous comparisons at Rothamsted, it has been evident, assuming that accurate serviceable instruments are used (and at present there is no valid excuse for considering any other kind), that the only important errors in records of precipitation are due to bad exposure and faulty methods of observation. The six different kinds of errors referred to by Mr. Horton are found in these two classes.

Some differences between gages under comparison can not be explained, but apparently if there are important differences between gages of different sizes they would have appeared somewhere in comparisons that have included the 0.001-acre gage, whose area is nearly 4 square meters, and the smaller ones having an area a thousand times smaller.

Comparisons of several patterns of gages at Blue Hill Observatory during a long period of time indicate that:

(1) Gages fitted with a Nipher screen made of wire cloth and having a diameter of at least twice that of the funnel are more efficient than unshielded gages during high winds.

(2) Apparently the best possible conditions are obtained when gages shielded in this way are placed with their funnels about 0.3 meter above the ground and inside an inclosure whose walls are composed of coarse wire cloth and placed at a distance from the gages equal to about twice their height.

Personal experience with various methods of measuring snow indicates that:

(1) Cylindrical "catch" gages, of which the length of the funnel is greater than one-third its diameter, should under no circumstances be used for measuring snow.

(2) The only moderately satisfactory "catch" gage has a very short funnel terminating in a receiver at least twice as large as the funnel and fitted with a Nipher screen as already described.

(3) It is best that "catch" gages for snow, particularly where an appreciable interval of time occurs between the end of the storm and measurement, should be made self-recording, for then it is possible to allow for evaporation and drifting due to increase or change of wind. Records from such instruments supplemented by surveys with samplers should yield more accurate information concerning the amount, rate, and duration of snowfall than is available with means in use at present. For use in sparsely settled regions it is easily possible now to produce gages of this kind capable of running several months with one winding of the clock.—*S. P. Fergusson.*